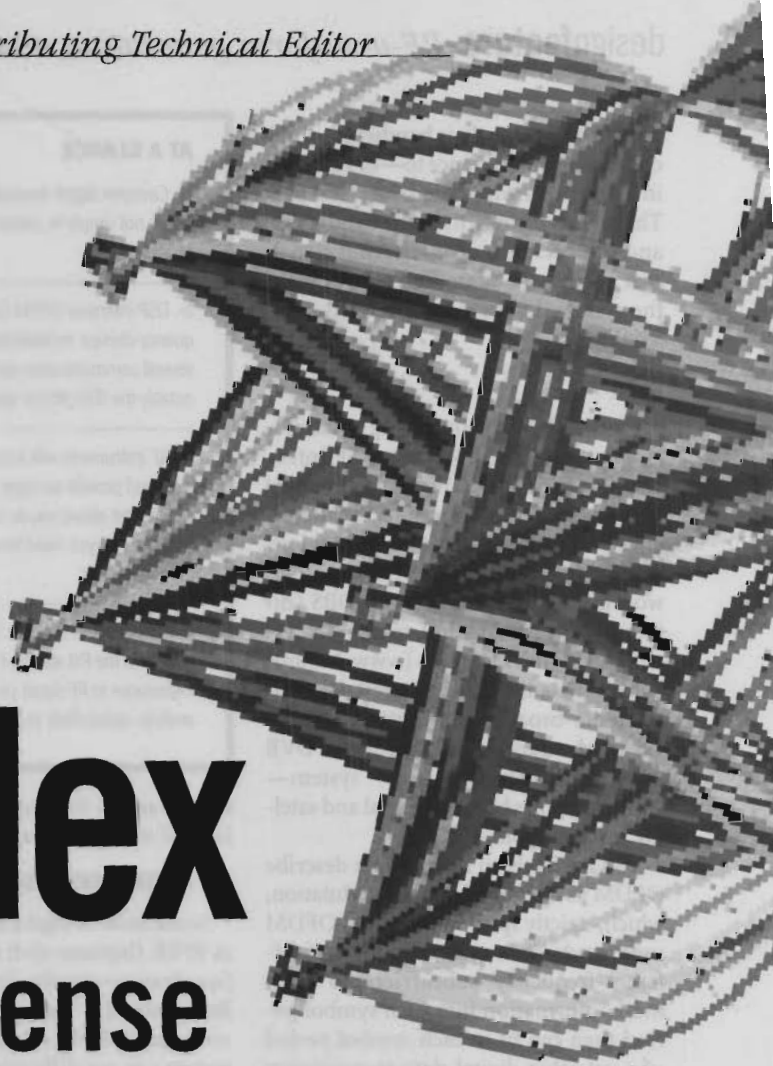


**BANDWIDTH IS LIKE LAND—
THERE'S ONLY SO MUCH OF
IT. THAT'S WHY THE ANALOG
MODULATION OF YESTER-
YEAR JUST CAN'T DO THE
JOB IN THE 21ST CENTURY.**

Complex —in every sense



IT'S HARD TO IMAGINE ANYTHING that better exemplifies 21st-century electronic technology's complexity than the signals that carry terabytes of information through air—and space. These signals travel through wired-network cables and optical-network fibers in

wireless LANs, advanced cellular systems, and terrestrial- and satellite-based multimedia digital-broadcasting systems. These communication and broadcasting systems are monumentally complex, and so are the information-packed signals they generate and transmit. Fortunately, you can probably use the signals and measure their key properties without completely understanding how they transport data or how the systems impress information onto multigigahertz RF carriers. Still, when selecting instrumentation or software to generate test signals or to determine how and why data sometimes becomes corrupted en route to its destination, you might

need a better understanding than you want to acquire.

The existence of still-in-its-infancy UWB (ultrawideband) technology, which uses hundreds of megahertz to send high-data-rate signals over distances of, typically, a few tens of meters or less, detracts nothing from the validity of the assertion that limited bandwidth and explosive growth in data volumes require ever-more-complex communications systems and signals. In fact, UWB reinforces the point. Instead of trying to find vacant spots in the RF spectrum in which it can place its signals, UWB transmits in frequency bands that other services occupy. UWB systems are

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designed to share their bandwidth without causing interference to—or receiving interference from—the other services. The high data rates, the wide bandwidth, and the presence of interfering signals that occupy the same frequencies make the system design extraordinarily challenging.

OFDM

One of the two competing technologies that underlie UWB is a DSP-intensive system called OFDM (orthogonal frequency-division multiplexing, **Reference 1**). OFDM is also a key technology in the IEEE 802.11 family of wireless-networking standards, in several DBS (direct-broadcast-satellite) television systems, in iBiquity Digital's (www.ibiquity.com) HDRadio TDAB (terrestrial-digital-audio-broadcasting) systems for the US market, and in the European DVB (digital-video-broadcast) system—which supports both terrestrial and satellite transmission.

You are likely to hear people describe OFDM as a form of digital modulation, which, strictly speaking, it is not. OFDM uses hundreds or even thousands of different-frequency subcarriers to pack more information into each symbol period than can fit in each symbol period of most other digital-data-transmission systems. Thus, OFDM uses fewer symbols of greater duration and complexity to transmit the same number of bits per second as several other digital-transmission systems. (Some people think of these as multiple symbols in one symbol period.) No increase in occupied bandwidth is necessary to maintain the data rate.

OFDM's long symbol times and correspondingly low symbol rates minimize ISI (intersymbol interference), which in RF communication is often the result of such signal impairments as multipath distortion. Multipath travel occurs when a signal arrives at the receiving antenna via several paths. One path might be direct from the transmitting antenna, whereas the others involve reflections from stationary or moving objects. By increasing the symbol duration to exceed the extra time the longest-delayed reflected signal takes to reach the receiving antenna, OFDM eliminates the ISI that such reflections normally cause. An additional benefit is spreading of the information among multiple carriers, which improves the signal's resistance to inter-

AT A GLANCE

- ▷ Complex digital modulation on RF signals is not simple to understand, generate, or analyze.
- ▷ DSP-intensive OFDM (orthogonal frequency-division multiplexing) is part of several communication standards—most notably the IEEE 802.11 series.
- ▷ RF instruments will incorporate PC hardware and provide an open Windows architecture that allows you to run the high-end software that you need to deal with complex waveforms.
- ▷ Cost-effective modular instruments that adhere to the PXI standard will also grow in importance in RF-signal generation and analysis—particularly in production test.

ference and to the frequency-response effects of multipath travel.

IT'S A DATA-TRANSMISSION SYSTEM

Some form of digital modulation, such as BPSK (biphase-shift keying) or QAM (quadrature-amplitude modulation, **Reference 2**), impresses information onto each OFDM subcarrier. An OFDM system can use different types of modulation on different subcarriers, and the type of modulation on any subcarrier can change from one instant to the next. That is, an OFDM subcarrier might use BPSK and then switch to QAM and back again, or it might switch to yet another form of modulation. You therefore probably should characterize OFDM not as a type of modulation, but as a data-transmission system.

In part, the magic of OFDM results from orthogonality among its many sub-

carriers. The idea that different-frequency signals can be orthogonal may take some getting used to because people most commonly think of orthogonality as a property of signals at the same frequency. For example, two same-frequency sinusoidal-signal components in quadrature—that is, displaced in time 90° from each other—are orthogonal because variations in the amplitude of either component don't affect the amplitude of the other. Similarly, modulating one OFDM subcarrier doesn't affect the system's other subcarriers, because the amplitude of each subcarrier's spectrum is zero at all of the other subcarrier frequencies (**Figure 1**).

OFDM systems sometimes use thousands of subcarriers. Compared with systems that are not based on OFDM and that use simple forms of modulation, such as BPSK, which transmits one bit per symbol, OFDM-based systems can theoretically transmit data at the same bit rate, despite a symbol rate that is lower in direct proportion to the number of subcarriers. Systems that combine OFDM with subcarriers that carry complex modulation, such as 64QAM (64-level QAM), can at least theoretically maintain the data rate while still further decreasing the symbol rate—by a factor of six in the case of 64QAM, which transmits six bits per symbol, because $64 = 2^6$.

HUNDREDS OF MEGAHERTZ

Generating a 2.5- or 5-GHz or higher frequency signal modulated with 64-QAM is difficult enough (**Reference 3**). Furthermore, at least two instruments—Rohde and Schwarz's SMU200A and Agilent's PSG series—can achieve modulation bandwidths of 200 MHz and 1 GHz, respectively, when you generate their baseband signals externally. Synthesizing

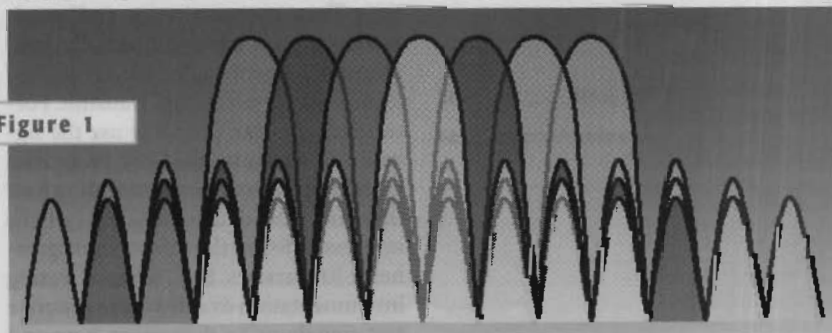


Figure 1
Looking at the spectrum of an OFDM signal's multiple subcarriers reveals how the system avoids ISI (intersymbol interference). The closely spaced carriers overlap. Nulls in each carrier's spectrum land at the center of all other carriers to produce zero ICI (courtesy Agilent).

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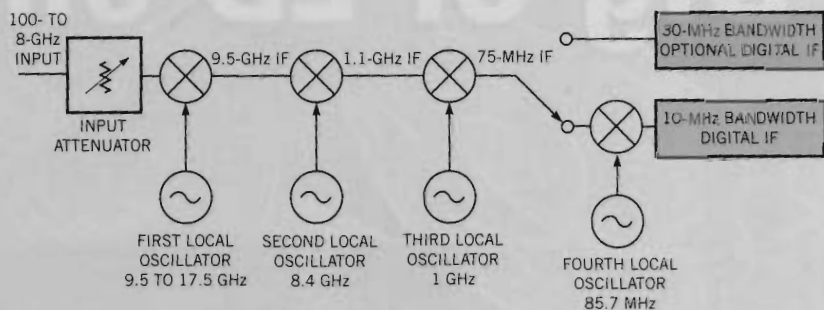


Figure 2

The IF (intermediate-frequency) section of Anritsu's Signature signal analyzer includes three—and, optionally, four—frequency-conversion stages.

The first stage upconverts to 9.5 GHz to avoid image-frequency problems. The other stages downconvert—ultimately, to the common IF of 10.7 MHz (85.7 MHz – 75 MHz = 10.7 MHz).

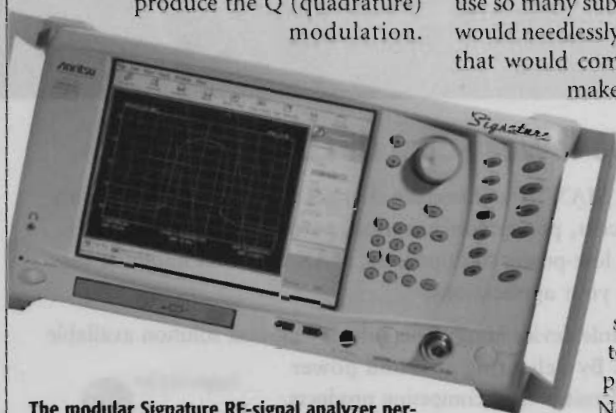
such signals and simultaneously simulating the impairments that can degrade them in typical environments further complicate the problem (Reference 4). Moreover, if instead of directly modulating the main carrier, QAM modulates an ensemble of hundreds or thousands of subcarriers (each carrying different information), and these subcarriers, in turn, modulate the main carrier, the signal-generation problem becomes mind-numbingly complex. Yet, modern RF-signal generators—often with the aid of software packages that usually run on separate PCs—easily handle this complexity.

Most RF-signal generators that produce modulated RF carriers contain a pair of DACs—one to produce an I (in-phase)-modulating signal and another to produce the Q (quadrature) modulation.

This IQ approach is not only conceptually straightforward, but also efficient: It enables each DAC to update at half the rate that would be required of a single DAC that synthesized the entire modulating waveform. Dividing the digital-to-analog-conversion function between I and Q DACs thus enables lower DAC-update rates, which simplify achieving the required resolution. Nevertheless, a few signal-generation products do use just one DAC to synthesize all of the modulation. You might think that signal generators that produce OFDM signals would use large numbers of DACs—perhaps one for each subcarrier—but instrument manufacturers report that it's simpler to mathematically synthesize and sum the subcarriers before converting to the analog domain. Because the systems use so many subcarriers, multiple DACs would needlessly present technical issues that would complicate the design and make the architecture uneconomical.

Analyzing received signals is at least as complex as is generating test signals. Traditionally, computational capabilities within instruments such as vector-signal analyzers have performed the analysis. Now, however, instruments that can export cap-

tured data have started to appear, and PC-based software packages that can perform analysis on the data sets are becoming available. According to the software publishers, several such postacquisition-analysis programs provide analysis capabilities that go well beyond those that traditional instruments include.



The modular Signature RF-signal analyzer performs signal and spectrum analysis on bandwidths as great as 30 MHz in the range of 100 Hz to 8 GHz. The instrument incorporates a PC that implements an open Windows XP-based architecture that streams data in real time into The MathWorks' Matlab software, which outputs and graphs the results of user-defined calculations as quickly as the instrument gathers the raw data (courtesy Anritsu).



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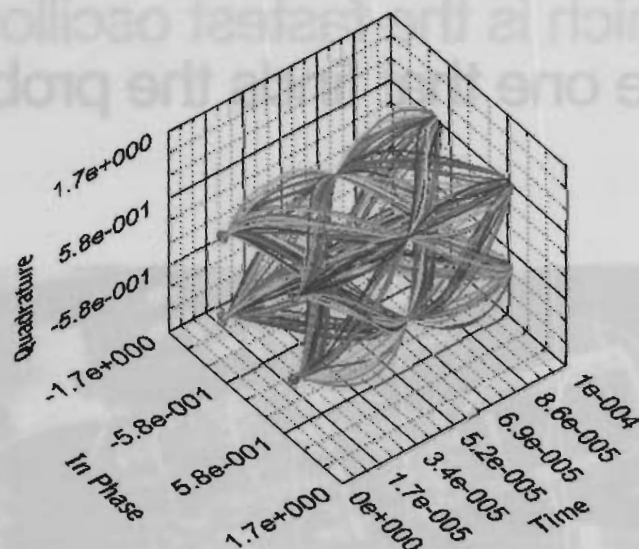
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This plot of a four-level phase-shift-keyed signal uses the 3-D-visualization capability of the Modulation Toolkit for National Instruments' LabView.

Moreover, these packages are program-
mable to a much greater degree than are
conventional instruments, making it eas-
ier to extract from the data exactly the
needed information.

PC INSIDE

In addition, following the lead of dig-
ital-oscilloscope manufacturers, RF-in-
strument makers are starting to produce
signal analyzers that contain PC hard-
ware and provide an open, Windows-
based operating environment. The Sig-
nature RF-signal analyzer from Anritsu
is a new instrument in this category. The
unit's specifications compete with those
of high-quality swept-frequency spec-
trum analyzers. Signature streams data
directly from its measurement hardware
to an analysis program that runs on the
PC within the analyzer. (Usually, the pro-
gram is The MathWorks' Matlab, but it's
sometimes the same publisher's Simu-
link.) This architecture thus transmits
data in real time to customizable, top-tier
math software, which displays complex
calculated results as quickly as the in-
strument acquires the underlying data.

Capabilities of this sort are useful in
applications such as the analysis of signal
impairments caused by reflections from
cars, airplanes, and other moving objects.
When you use the same software in a
more conventional setup, you can't even
begin the analysis until you have ac-
quired a complete data set and exported
the file to a separate PC. With the built-
in PC and high-speed links to the analy-
sis software, the correlation with the ex-

ternal events is immediate and obvious;
in the more conventional setup, you
must not only wait to see the results, but
also try to figure out what caused them.

Still, adding a PC inside an RF instru-
ment, such as a vector-signal or spectrum
analyzer, in which SNR (signal-to-noise
ratio) is a key parameter, exacts a penal-
ty on instrument designers. PCs are no-
torious sources of electrical noise. The
clock frequencies of most signals that
travel through pc-board traces within a
PC—as opposed to signals confined
within IC packages—are relatively low
compared with the signals of greatest in-
terest in RF measurements. However, the
harmonics can easily enter frequency
ranges of interest. Avoiding unwanted
signals of this sort requires great care in
shielding and filtering, which increases
an instrument's cost, weight, and—
sometimes—size.

FREQUENCY CONVERSION

Instruments that produce or analyze
information-bearing multigigahertz sig-
nals inevitably take advantage of fre-
quency conversion, and most do so more
than once (Figure 2). Heterodyne fre-
quency conversion uses not multiplica-
tion of frequencies but rather mixing,
which is a process of multiplying signal
waveforms and filtering the result. Wave-
form multiplication is modulation or de-
modulation, and it produces new signals
at the input signals' sum and difference
frequencies.

Filtering, which historically has been
accomplished in the analog domain, is



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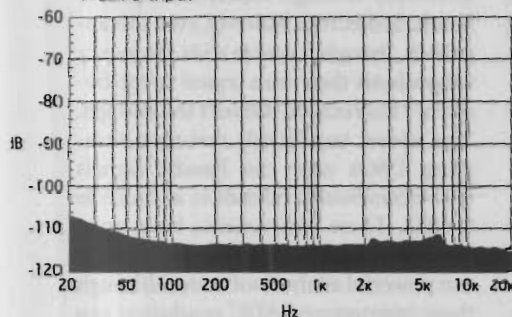


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now often accomplished in the digital domain using DSP technology. Although you can construct digital filters with characteristics that designers of analog filters only dream about, digital filters require digital signals, and, if the signals begin life in the analog domain, an ADC must precede the DSP. Without special architectures, limitations on the resolution or dynamic range of the ADC or the T/H (track-and-hold) circuit that precedes it can make it impossible to construct suitable digital filters.

Even as modulation becomes more complex and spectrum-efficient, the bandwidth that some modulated signals occupy has increased. Swept-frequency spectrum analyzers—even instruments that make substantial use of DSP—cover wide bandwidths by looking sequentially at narrow slices of the frequency domain. The problem with this approach is that it tacitly assumes that a signal's spectrum does not vary materially over time. However, if events come and go, and the spectrum analyzer is examining a narrow bandwidth surrounding Frequency A when an event of interest is taking place at Frequency B, the spectrum-analyzer display doesn't reveal it.

EXAMINING A WIDE SWATH OF SPECTRUM

Looking simultaneously at a wide swath of the frequency domain is a job for DSP-based analyzers. Several companies, including the industry's largest instrument supplier, Agilent Technologies, call their DSP-based instruments VSAs (vector-signal analyzers). Tektronix calls its units RTSAs (real-time spectrum analyzers). Tek insists that RTSA isn't just another name for a VSA and that RTSAs

offer capabilities that VSAs don't. An example is event-driven triggering, which allows capturing data only when the instrument detects a phenomenon of interest. Tek also boasts of RTSAs' deep memory. However, memory deep enough to store several seconds of unprocessed data is also a property of some VSAs, although Tek's mix of event-driven triggering and deep segmented memory appears unique and could give the company an edge in effective memory depth. Compared with swept-frequency spectrum analyzers, however, most DSP-based analyzers, regardless of their name, have a serious drawback: Their dynamic range does not equal that of the highest performance swept-frequency instruments.

Several DSP-based analyzers can handle signals with bandwidths as great as 80 MHz. And you can make a wideband analyzer cover a bandwidth wider than its normal maximum by having it step sequentially through adjacent frequency bands. Sometimes, however, even this approach, though it covers wide frequency ranges faster than can a typical swept-frequency instrument, still isn't fast enough. The widest bandwidth real-time-sampling DSOs now can handle signals whose bandwidth extends to as much as 8 GHz. These instruments have open Windows architectures, enabling them to run powerful analysis software. Although these instruments' ADC resolution can seem inadequate for communication-signal analysis, the approximately 50 dB they provide is often adequate.

So far, Tektronix seems to be the only company that has announced the capability to use multiple synchronized wide-

FOR MORE INFORMATION...

For more information on instruments and software for generating and analyzing RF signals that contain complex digital modulation, contact the following companies. When you contact them directly, please let them know that you read about them in *EDN*.

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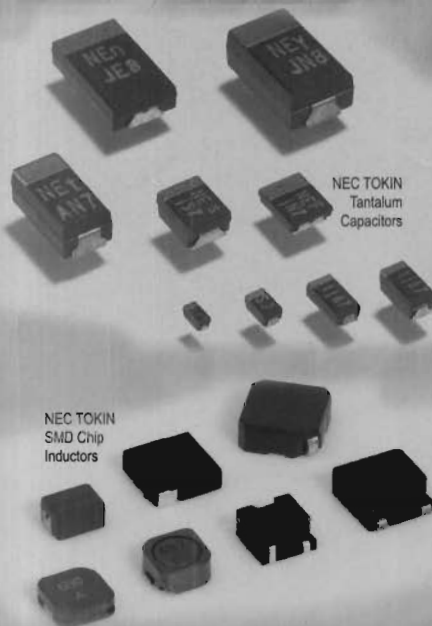
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band analyzers tuned to adjacent frequency bands. This capability is useful in applications that demand simultaneous processing of information contained in a range of frequencies wider than one analyzer can handle. Other companies report that they are working on similar approaches, and it seems only natural that in the not-too-distant future, some company will announce as a standard product a system that combines multiple synchronized analyzers.

PXI

A relatively new development in RF instrumentation is the advent of instruments such as RF-signal generators and analyzers in the modular-PXI format. Both Aeroflex and National Instruments offer PXI RF instrumentation, so you may consider the two companies' PXI RF-product lines to be competitors. The product-design philosophies differ greatly, however. NI, as it does with nearly all of its PXI products, takes the position that its modular-RF instruments are lower cost alternatives to general-purpose benchtop units. Because software determines the functions the modules perform and controls the modules' operation, NI claims that modular instruments are easier than general-purpose instruments to tailor to your application. Meanwhile, Aeroflex, which also makes a broad line of benchtop and portable instruments, characterizes its PXI modules as tightly focusing on specific applications—primarily in production test.

NI people often deride benchtop instruments as oversized, overpriced, hard-to-use dinosaurs. So far, however, NI's most visible success with its PXI RF products is in ATE (automatic-test equipment) for production test of RF ICs. The company has thus far not presented a great deal of evidence that the PXI RF line is making significant inroads into R&D labs. Assuming that NI's claims of modular instruments' operational superiority over general-purpose instruments are valid, it is incumbent upon NI to ensure—and communicate the news—that R&D engineers in RF design recognize and embrace the advantages of modular instrumentation.

One reason that such a demonstration



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Contributing Technical
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with RF instrumentation is a complex undertaking is that, if you sit down with a stack of data sheets intending to compare the performance of a group of instruments that nominally perform equivalent functions, you will soon find that you are comparing apples, oranges, tomatoes, and bananas. The test conditions under which a data sheet

specifies performance are important, and it is rare to find two instruments that specify a measurement under the same test conditions. So, to do a thorough job, you would need a well-equipped test lab and, ideally, multiple samples of all of the instruments you are evaluating. Fat chance! A better approach is to speak candidly about your requirements with and ask pointed questions of application- or sales-engineering professionals from the two, three, or four companies whose products—based on some initial study—appear to best meet your needs. □

REFERENCES

1. Fischer, Walter, *Digital Television—A Practical Guide for Engineers*, ISBN 3-540-01155-2, Rohde & Schwarz/Springer-Verlag, 2004.
2. Agilent Technologies, *Digital modulation in Communications Systems—An Introduction*, Application Note 1298, Document No. 5965-7160E.pdf.
3. Anderson, Jack, and B Burrows, *Feature and Specification Considerations When Selecting a Digital Signal Generator*, Aeroflex Corp, 2004, www.aeroflex.com/aboutus/pressroom/articles/Aeroflex-Signal-Generation.pdf.
4. Anderson, Jack, *If You Build It, You Have to Test It...Challenges and Solutions in Broadband-Communication-Systems Test*, Aeroflex Corp, August 2002, www.aeroflex.com/aboutus/pressroom/articles/If_You_Build_It.pdf.
5. Agilent Technologies, *Testing and Troubleshooting Digital RF-Communications-Receiver Designs*, Application Note 1314, Document No. 5968-3579E.pdf.
6. Agilent Technologies, *Designing and Testing CDMA2000 Mobile Stations*, Application Note 1358, Document No. 5980-1237E.pdf.

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